the special properties of fluorides (compared to other halides) arise from the lower solubility or stability of lower fluorides in fluoride melts, compared to the analogous reduced compounds in the other halides. Considerable work on electrode-reaction mechanisms and on the chemistry of fluoride melts remains to be done before these tentative conclusions can be firmly substantiated.

Summary

A general process has been developed for the electrodeposition of eight of the nine refractory metals of groups IVB, VB, and VIB as dense coherent deposits. It consists essentially of the electrolysis of a solution of the refractory metal fluoride in a molten alkali-fluoride eutectic mixture, and has been shown to deposit a coating, unalloyed with the substrate, by a process that obeys Faraday's law. Some evidence exists that the electrode-reaction mechanism by which coherent coatings are deposited from molten salts incorporates an irreversible metal-producing step.

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Archeology and Its New Technology

Archeology comes of age with an interdisciplinary approach in expanding its research horizons.

Froelich Rainey and Elizabeth K. Ralph

In archeology, as in all branches of research, postwar technology has opened new horizons—not simply as a matter of increased efficiency, but as a remarkable acceleration in our acquisition of knowledge of man in his environments. Moreover, archeology is no longer limited to the "what" of prehistory, but is now making use of heretofore unsuspected methods of gleaning the "when," the "how," and, we hope, the "why" of man's prehistory. Perhaps of even greater importance, however, is the fact that some of those in the humanities, to their quiet surprise, find themselves working directly with physical scientists on specific research projects to solve technical problems of concern to both. In a small way, we are making the staggering crossover between the world of the sciences and that of the humanities in a practical and, indeed, pleasant day-by-day experience. The physical scientist is being asked to provide a system of absolutes where few existed before, and the archeologist is learning that all chemists are not categorically alchemists. The happy result is that archeology has fallen heir to a number of these proliferating techniques and has acquired a new sophistication.

This article emphasizes those new techniques and the improvements in existing ones with which we have been working; in addition, a few pertinent although previously described techniques and developments at other institutions are outlined. Most of these techniques share a common ground in the application of some atomic or nuclear phenomenon: thermoluminescence dating is based on those electrons rendered metastable as a result of radiation damage; optical absorption magnetometers depend on the splitting of atomic energy levels; and a number of dating and analytical techniques rely on natural radioactive decay within the nucleus, or on transformations resulting from induced radioactive bombardment.

Of all the postwar developments, radiocarbon dating has had perhaps the most profound effect upon archeology. Literally thousands of radiocarbon dates obtained since the initiation of the method by Arnold and Libby (*1*) have aided in both the establishment and the revision of many archeological and geological chronologies. And the methods of detection of natural carbon-14 (primarily proportional gas counting techniques) are now sufficiently sensitive to permit investigation of some of those problems inherent in the radiocarbon dating method.

For normal dating calculations, the method assumes the constancy in past times of the atmospheric and oceanic inventories of carbon-14. But a fluctuation in the amount of carbon-14 in the atmosphere during a B.C. era was first suspected from the discrepancies found between radiocarbon dates and the es-

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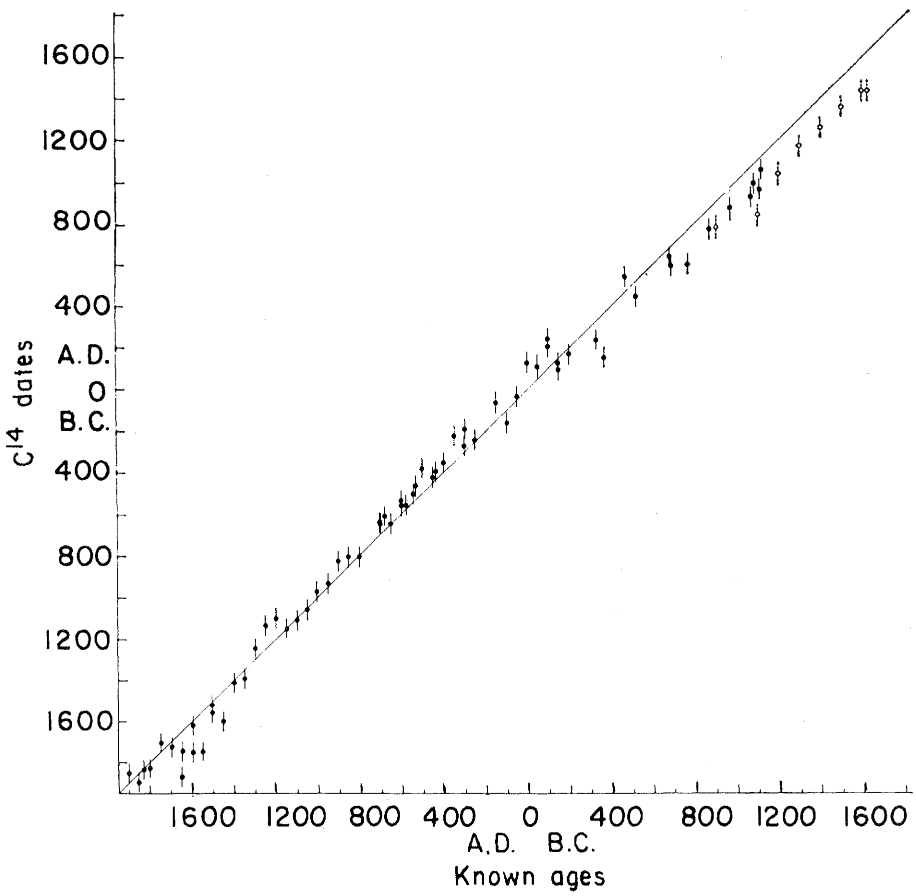

Fig. 1. Carbon-14 dates from the University of Pennsylvania plotted against known ages for tree-ring-dated sequoia (solid lines) and bristlecone pine (broken lines) samples. Carbon-14 dates are corrected for possible fractionation errors by C^{13}/C^{12} determination. (The uncertainty in the C^{13}/C^{12} measurements is not included.)

tablished chronologies (*2*) for the early Egyptian dynasties—carbon-14 dates for this era (*3*) are consistently later than expected by 300 to 500 years. Radiocarbon laboratories began to view the entire dating time range with circumspection, with the result that several laboratories have suggested that the atmospheric inventory has not been precisely constant.

Now, dendrochronology is providing a means of assessing these fluctuations, perhaps as far back as 5000 B.C. The Laboratory of Tree-Ring Research at the University of Arizona has been providing dendrochronologically dated sections of bristlecone pines (*Pinus aristata*) whose ages extend far beyond the range of the well-known *Sequoia gigantea*. A plot of our carbon-14 dates for dated sequoia and bristlecone-pine sections is shown in Fig. 1 (*4*). Oscillations of the carbon-14 inventory noted by other laboratories (*5*) in the A.D.-1400-to-1700 range are confirmed, yet carbon-14 dates from A.D. 1400 to 100 B.C. fall consistently just above the true-age line. A divergence (recorded also by Damon, Suess, and others), which seems to increase with age, is apparent in the earlier periods. The average deviation of the 1600 and 1625 B.C. bristlecone-pine samples (the earliest thus far dated in our laboratory) is 176 years. [These dates were calculated with the 5730-year half-life value for carbon-14, which is the present best estimate. Ages calculated upon this basis are 3 percent greater than those calculated with the previous 5568-year value determined by Libby (*6*).]

These dates already are providing correction factors for archeological dating, and still earlier adjustments will be determined as dendrochronologically dated material becames available. But of equal importance is the determination of the magnitude and duration of the significant fluctuation in the B.C. era, for such information may lead to an understanding of its origin. Was it caused by variation in the cosmic-ray intensity, by changes in the intensity of the earth's magnetic field, by a difference in the equilibrium conditions (that balance between atmosphere and oceans), or by some as yet undetermined combination of several factors?

Thermoluminescence Dating

The radiocarbon method for the absolute dating of ancient organic materials has profoundly altered our knowledge of man's past. We now know, for example, that the end of the Ice Age was closer to 10,000 than 20,000 years ago; that food crops were grown in Mexico by 5000 to 6000 B.C., almost as early in the Americas as in the Near East; and that men were building stone-walled towns in Palestine by 7000 B.C. But there has always been one serious drawback to archeological radiocarbon dating—the matter of association of the sample with the event for which a date is wanted. In every case, the archeologist must assess the relationship between the age of the organic material (charcoal, wood, burned bone, shell, and so forth) presumably associated with the artifact, and the artifact itself. Moreover, there is often too little organic material of suitable association to provide an adequate series of samples for reliable radiocarbon dating. There is thus every possibility that many of the published archeological dates may be, to some degree, erroneous.

The new thermoluminescence method of dating pottery avoids these hazards, for it dates the artifact itself rather than presumably associated materials which may or may not be strictly contemporaneous. Moreover, in those sites where pottery is found, it usually appears in abundance, so that samples for analysis are plentiful. Archeological chronologies for human events since Neolithic times are often based on sequences of distinctive pottery types, and many of the dates for these sequences are still more relative than absolute. The thermoluminescence method should provide a means of fixing in time those pottery types which have become horizon-markers of post-Mesolithic prehistory.

Workers in the general field of thermoluminescence studies have made measurements for a variety of purposes, such as those fundamental physical studies by Halperin *et al.* (*7*), studies of meteorites by Houtermans *et al.* (*8*) and age estimation of sediments by Zeller *et al.* (*9*). But the suggestion that thermoluminescence might provide a means of dating pottery was first published by Daniels *et al.* (*10*); and the use of the technique for archeological dating was investigated further by Kennedy and Knopff from 1958 to 1960 (*11*).

Thermoluminescence in pottery is due to the fact that radiations from traces of radioactive elements within the pottery bombard the other constituents of the clays and raise the electrons to metastable levels. When the pottery is heated, as in firing, each electron falls back into its stable position, emitting a photon of light. When, much later, the pottery is reheated, the amount of thermoluminescence observed is representative of the accumulated radiation damage, and hence of the time that has elapsed since the original firing of the pottery. For a relatively short time after an object has been heated to a temperature of perhaps 400° to 500°C and its electrons have emitted their thermoluminescence, no further light may be obtained by reheating; consequently, recently fired ceramics or freshly cooled lava, which have all electrons in stable sites, should show no thermoluminescence.

On the assumption that the major portion of this damage is caused by alpha bombardment from traces of uranium and thorium, or is proportional to it, we have constructed low-background zinc sulfide screens and associated components for detection of this low-level alpha bombardment. The samples are counted in "infinitely" thick layers, with the result that only comparative values are obtained. We have found, thus far, that measurement of the alpha component is sufficient, since correction factors for potassium-40 (the other most prevalent radioactive isotope in pottery), obtained from measurements of potassium contents, did not improve the age correspondence.

Our numerous preliminary experiments on the detection of photons emitted upon heating indicated that only very rapid heating and necessarily thin layers of powdered potsherds would permit detection of maximum light output. Rapid heating (now 16°C per second) is essential, or the high sensitivity required to detect the small amount of visible thermoluminescence also permits the detector to pick up the onset of heat radiation from neighboring heated materials. This rapid heating unfortunately prevents discrimination of separate peaks at low, medium, and high temperatures. Sample heating is carried out in a nitrogen atmosphere to prevent possible combustion of organic particles and potential spurious changes in intensity due to the presence of oxygen. The problem, therefore, is quite different from that of detection of thermoluminescence from crystals such as alkali halides, for which experiments are normally carried out between room and liquid-oxygen temperatures.

Very thin uniform layers of pottery are obtained by first grinding the sherds in a ball mill to less than 200 mesh. This powder is then mixed with silicone oil and applied to aluminum foil by means of a silk screen in a "spot" 1.2 centimeters in diameter, so that a thin, uniform, and stable coating of pottery is produced on the foil. The glow curve apparatus is shown in Fig. 2.

Variations in the susceptibilities of clays to radiation damage demand that some correction factor be applied. To measure the susceptibility of a clay to this damage, a source with much greater intensity than the natural bombardment is used in order to duplicate in a short time the original radiation damage. We have found a moderate x-ray exposure (30 kilovolts, 12.7 megamps, 1 minute) to be sufficient for this bombardment. Even though samples taken from a single piece of pottery have been ground and mixed thoroughly, we have found large variations among them in their susceptibilities. Thus the correction factor obtained through artificial bombardment must be applied to samples from the same piece that is measured for natural thermoluminescence. Fortunately, our silicone mounting oil permits this. Thus when each sample is heated, its natural thermoluminescence measured, and the sample bombarded with x-rays and then reheated, application of the area of the glow curve as a correction factor provides some improvement in the consistency of results.

The glow curves induced by x-ray bombardment exhibit a low-temperature peak, or peaks, which are unstable and decay within 1 to 2 weeks. These unstable low peaks have already disappeared from the natural glow curves as a result of the thermal environment and possible decay. Therefore, after artificial bombardment one must wait

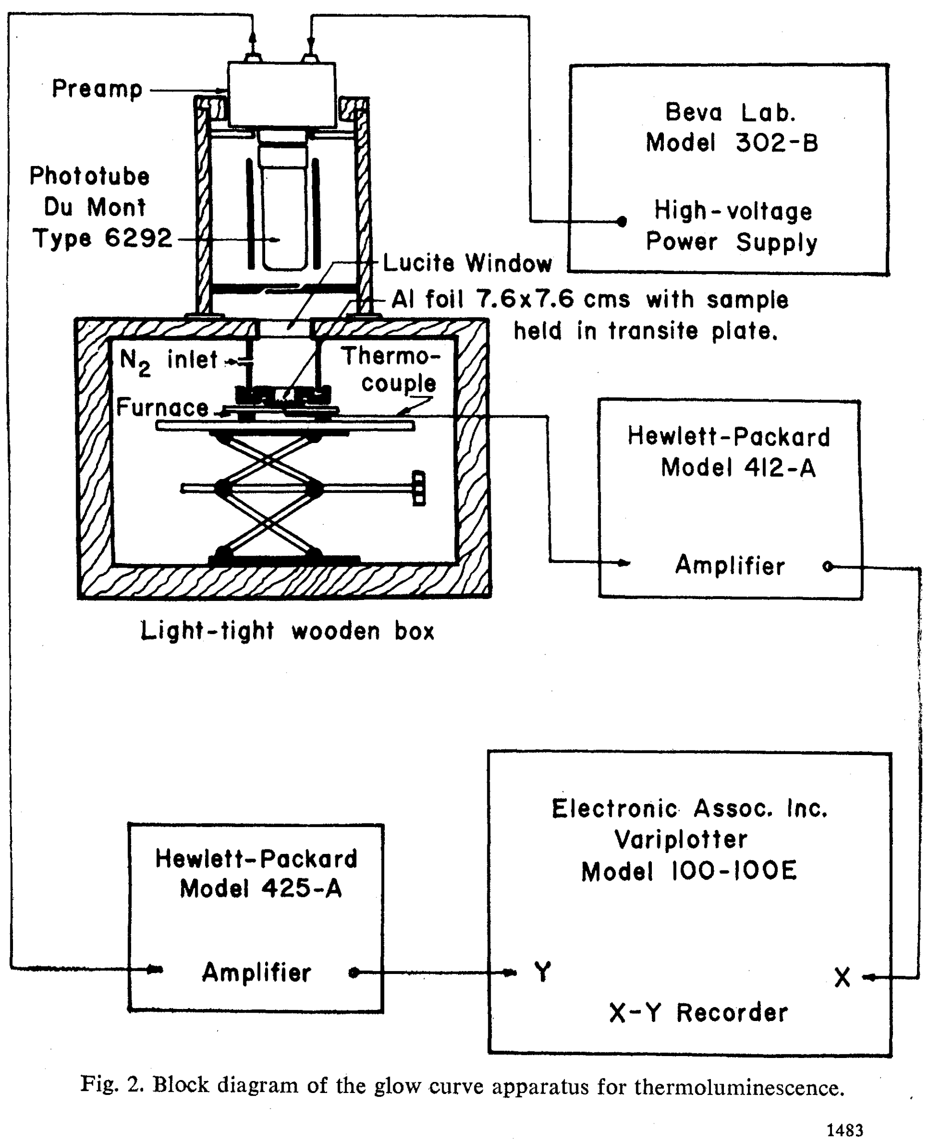

Fig. 2. Block diagram of the glow curve apparatus for thermoluminescence.

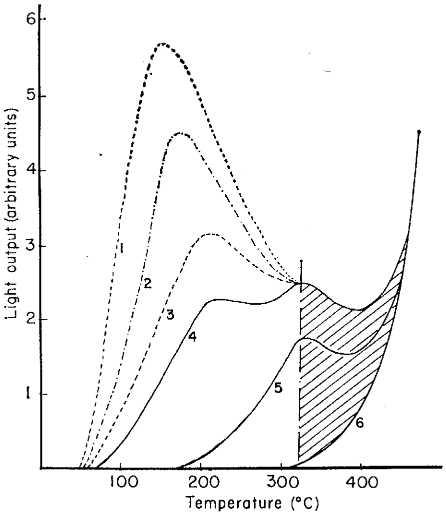

Fig. 3. Thermoluminescence glow curves. 1, Artificial glow immediately after irradiation with x-rays; 2, artificial glow 24 hours after irradiation with x-rays; 3, artificial glow 1 week after irradiation with x-rays; 4, artificial glow 2 weeks after irradiation with x-rays; 5, natural glow curve; 6, background curve from heat radiation. The hatched regions are the significant areas for both the natural and artificial thermoluminescence.

for these low peaks to decay in order to obtain a reliable correction factor. This procedure is supported by recent experiments of E. J. Zeller (*12*) and others at Brookhaven National Laboratory, which indicate that, initially, after artificial exposure, only the low-temperature traps are filled; later, by some means as yet unexplained, traps corresponding to higher temperatures and peaks become filled. Ideally, only the area under the high temperature peak should be measured, but, as mentioned before, successive peaks are unresolved in the rapid heating necessary for this weak thermoluminescence. A week or two after x-ray bombardment, the low-temperature thermoluminescence does decay, and a small but discernible higher peak appears. When the half-area of this higher peak is used as the correction factor, good age correspondence is obtained (see Fig. 3). The improvement in the uncertainty of the measurements due to the x-ray correction factor is shown in Table 1.

A series of sherds from the Solduz Valley in Iran from 5500 to 900 B.C. (dated through associated charcoal samples in our Radiocarbon Laboratory) have been analyzed, as have samples from the Sybaris region of Italy, and from Pecos pueblo in the southwestern United States (see Fig. 4). The uncertainty of all measurements is still greater than desired, but it is much smaller for the later (300 B.C. and after) sherds from Italy and Pecos than for the earlier ones from Iran. Better results may be expected from pottery of better quality.

The thermoluminescence method is limited in application to the past 8000 or 9000 years (the period since the beginning of pottery manufacture) and, at the present time, the margin of error (at least ±300 years for the older samples) is still too great to satisfy many archeologists. But this is only one of several methods of dating now being developed and, as with all such methods, its accuracy should improve with our increasing development of the technique.

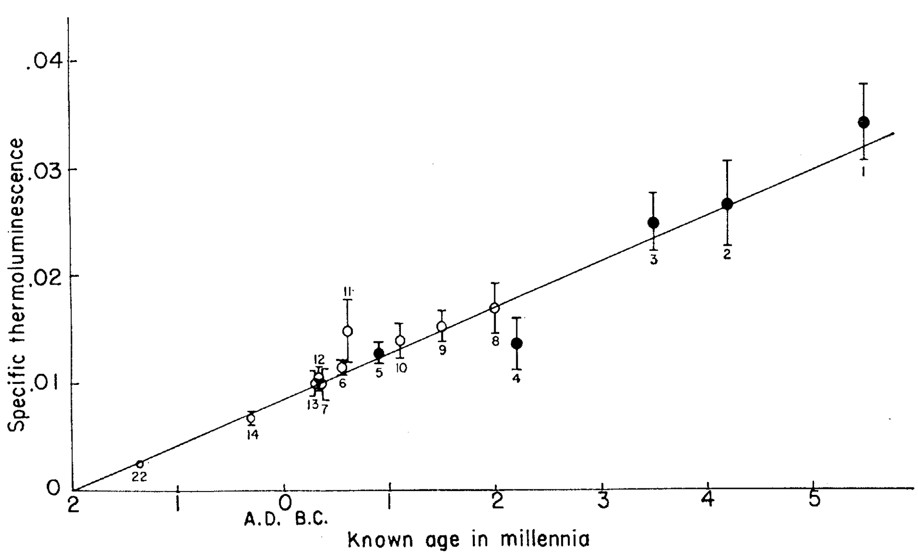

Fig. 4. Specific thermoluminescence plotted against known ages for samples from Iran (Nos. 1 to 5 and 8 to 11), Italy (Nos. 6, 7, 12, 13, and 14), and the United States (No. 22). The solid dots represent averages of replicate runs of two or more contemporaneous samples; open circles, one sample only.

Potassium-Argon Dating

Significant advances have been made recently in another radioactive dating method, the potassium-argon (K^{40}-A^{40}) method. The method is dependent upon the radioactive decay by electron capture of potassium-40 to argon-40. Normally, the potassium is present in quantities sufficient for measurement by ordinary methods such as flame photometry; but the isotopes of argon must be measured with higher precision in a mass spectrograph. The determination of argon isotopes other than argon-40 provides a correction factor for the possible inclusion of atmospheric argon, and therefore complete extraction of argon is mandatory. It is improvements in the argon extraction procedure which have permitted Evernden and Curtis (*13*) to report higher precision for ages of less than one million years.

Because of the long half-life of potassium-40 (1.3×10^9 years), the potassium-argon method has been useful primarily for dating in the range of millions of years. But with improvements in measurement techniques, dates are readily obtained in the 400,000-year range. Evernden and Curtis (*13*) have reported high-precision dates as late as 30,000 years ago on sanafines. The present difficulty is one of finding contemporaneous samples for cross-checks between potassium-argon and carbon-14 methods. Those natural phenomena which create materials suitable for potassium-argon dating tend to volatilize associated carbon compounds suitable for carbon-14 dating.

Perhaps the most publicized dating efforts utilizing the potassium-argon technique is that of the Olduvai Gorge chronology and the determination of the age of *Zinjanthropus* (*13*). The dating of Olduvai Bed I has been supported by an entirely different technique—fission-track dating (*14, 15*).

Fission-Track and Thorium-230 Dating

In this method the hydrofluoric acid etching of the surface of crystal or glass reveals radiation-damage tracks due to the spontaneous fission of uranium-238 after the solidification of the sample. To determine the rate of bombardment, the uranium content is determined indirectly but with great sensitivity [contents as low as one-thousandth part per million (*16*)] by fission of uranium-235 induced by neutron irradiation. The age of the material is then a simple function of the ratio of the numbers of observed tracks resulting from natural fission to those resulting from the induced fission. Fleischer *et al.* (*15*) reported the dating of glass in volcanic pumice from Olduvai Bed I as 2.03 ± 0.28 million years; potassium-argon dates of 1.85 and 1.76 million years from the same deposit provide a comforting agreement between the techniques. Similar correspondence has also been obtained with tektites (*15*) and other materials in the range of millions of years.

In man-made glasses, the time elapsed for track formation is so short that fission-track dating is limited to those glasses with fairly high uranium content; this, in turn, limits the archeological applications of the method. In natural glasses, a uranium content of 1 to 2 parts per million makes possible the dating of artifacts older than 8000 years, and with 3 parts per million, artifacts only 2000 years old can be dated, although with less precision (*17*).

Other dating approaches are being tried in attempts to bridge time gaps between methods and for correlation purposes, as in the recent comparison

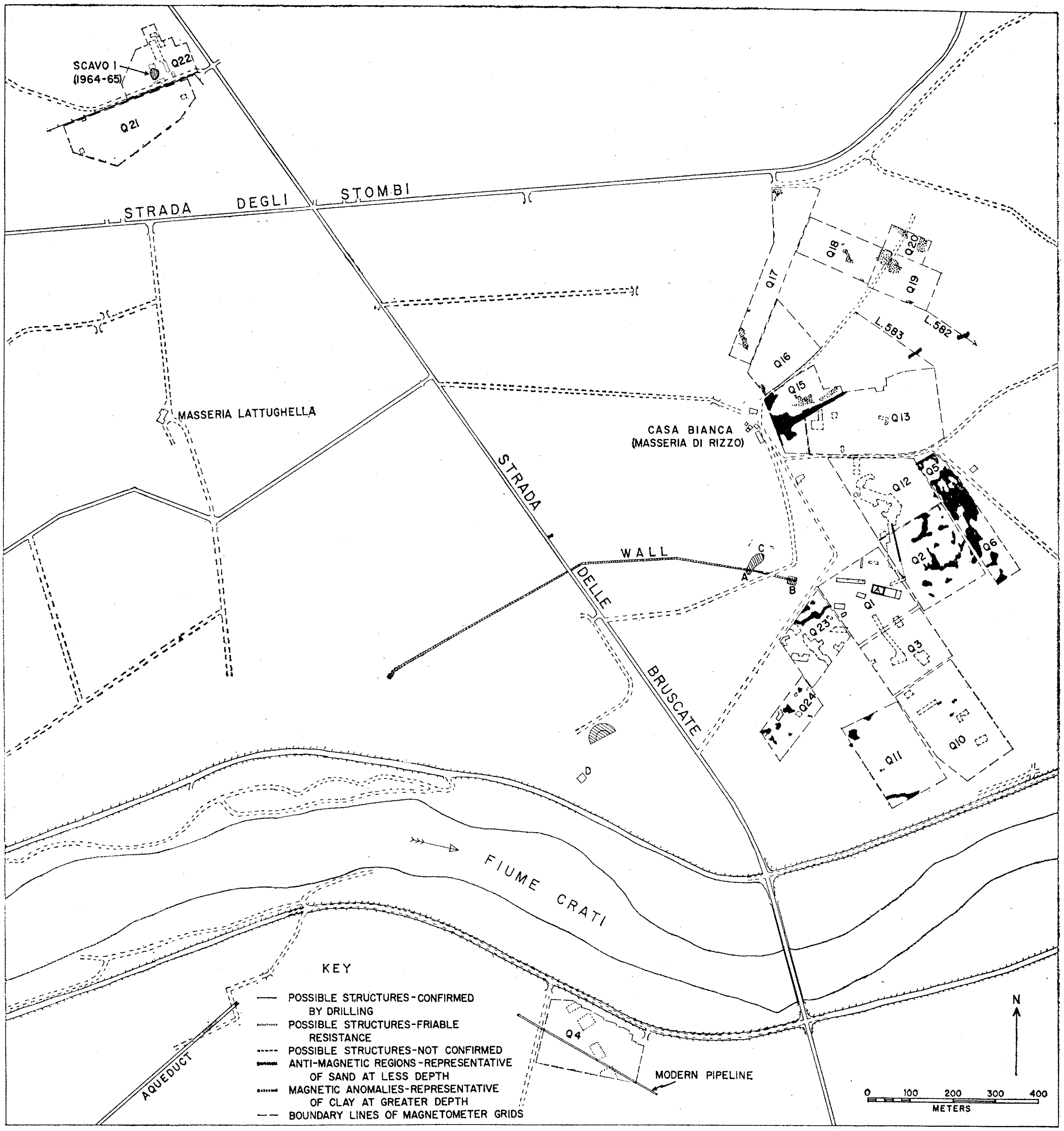

Fig. 5. Map showing area of concentration of archeological features and deposits on the plain of Sybaris, Italy. Locations of the long wall, test excavations (hatched areas), and grids made with the cesium magnetometer are shown. Within the grids, probable features detected are designated.

of thorium-230 and carbon-14 ages for carbonate materials by Kaufman and Broecker (*18*). Thorium-230 dating is based upon an inequilibrium in the uranium series; because of the deficiency of thorium-230 (half-life, 75,200 years) with respect to its parent uranium-238 in natural waters, carbonates precipitating in nature should show initial inequilibrium in the uranium-238 series. Kaufman and Broecker's results indicate that samples in which radium-236 is at equilibrium with thorium-230 and the concentration of thorium-232 is not unusually large, satisfactory agreement with carbon-14 ages may be obtained. Even though the rather stringent requirements of reliable thorium-230 dating limit its applicability, its range of 10,000 to 200,000 years is optimum for filling the time region for which other methods are not available.

The primary technique of archeology is excavation. But, as labor costs become higher all over the world, and as modern civilization encroaches upon ancient sites, there is a desperate need to accelerate and facilitate the finding of structures at known sites and the locating of lost or unsuspected cities

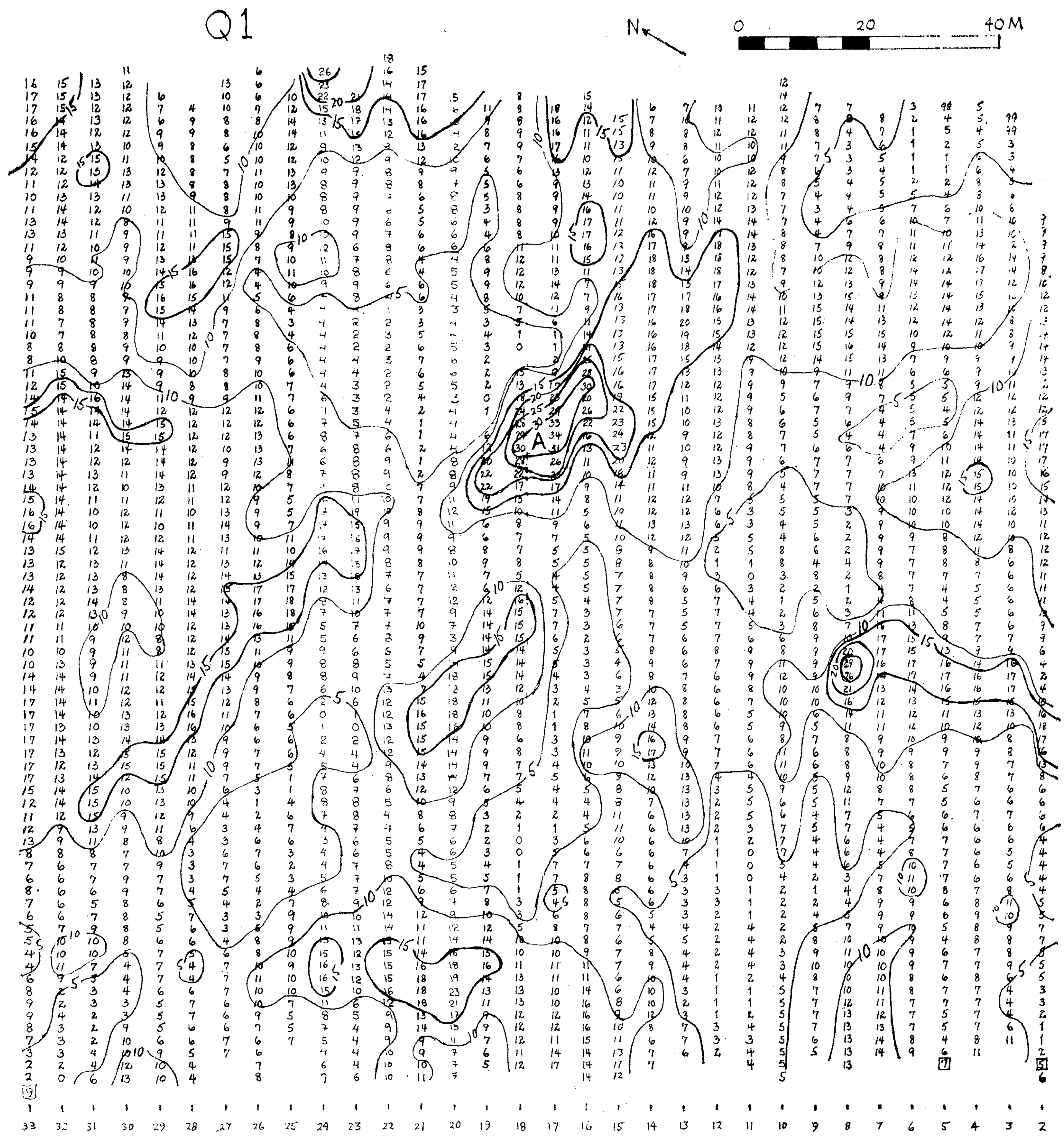

Fig. 6. Grid (or *Q*) 1 made with the cesium magnetometer. Contours of equal magnetic intensity are shown in "differential" units (1 unit ~ 0.5γ) and are drawn at intervals of 5 units. The grid has been photographed from the original data and shows also the numbers as recorded in the field notebook. The anomaly (*A*) representative of "structure" *A* is approximately in the center of this grid.

and sites. In this respect, the physical scientist has helped with a variety of instruments for the detection of buried archeological features.

Resistance apparatus, used to measure the electrical conductivity of surface soils, can be applied effectively to locate many relatively shallow archeological features, so long as there is sufficient difference in moisture or some other quality to cause a difference in soil conductivity. The past 15 years have witnessed the location and mapping in England, as in Italy and Germany, of many ancient ditches, refuse pits, and buried constructions by this method. A most practical, light-weight, and inexpensive instrument is the German-developed "Geohm." Tests of the instrument carried out by the Applied Science Center of the University (of Pennsylvania) Museum at a number of sites in the United States, Canada, Central America, Italy, and the Near East unquestionably proved its usefulness under suitable geophysical conditions. It was found to be especially useful for the location of shallow-depth structures at historic sites in the eastern United States and Canada, where more recent refuse, power lines, and so forth, preclude the use of magnetic methods. But field operation is slow, and detection of features more than 1 or 2 meters below surface is rare.

The proton magnetometer was developed for archeological use by E. T. Hall and M. J. Aitken at the Research Laboratory for Archaeology and the History of Art at Oxford. This instrument measures small differences in the magnetic intensity in surface soils, with a maximum sensitivity of approximately 1 gamma (or 10^{-5} oersted). The proton magnetometer is highly effective in locating kilns and fire-pits, as well as other fired archeological remains, and, under auspicious conditions, buried stone structures and earthworks. In Italy, for example, we very quickly located the rock-cut tombs at Tarquinia and Cerveteri on magnetic contour maps prepared from magnetometer surveys over known cemetery areas; in 1961 we were able to locate an average of five or six tombs per day of survey. Again, on the plains of Sybaris in southern Italy, we were able to trace a buried stone wall for more than 1300 meters in a few days (see Fig. 5) and to locate other stone and brick structures not more than 3 meters beneath the surface. Success with this instrument is due to the magnetic contrast between the buried structures and the slightly magnetic clays surrounding them.

Table 1. Results of replicate runs, with means and deviations, for one sample (No. 6, about 550 B.C.) from the plain of Sybaris. Alpha activity was 32.5 ± 1.2 counts per hour. Specific thermoluminescence, 0.0114 ± 0.0007.

Area of glow (cm^2) Natural	Area of glow (cm^2) Artificial	Ratio between areas (natural/artificial)
17.3	46.5	0.372
14.0	37.5	.373
14.9	43.5	.343
17.8	51.0	.349
17.0	48.0	.354
20.3	57.0	.356
21.5	54.0	.398
13.0	39.0	.333
18.8	49.5	.380
22.0	57.0	.386
16.0	44.4	.360
26.0	69.0	.377
16.1	46.5	.346
20.3	51.0	.398
15.0	63.0	.397
23.5	61.5	.382
23.0	60.0	.383
16.5	45.0	.367
19.1 ± 3.8	51.3 ± 8.6	0.370 ± 0.019

Another magnetic instrument of comparable sensitivity has been developed recently at Oxford—the flux-gate magnetometer (*19*). The detectors consist of flux-gate elements—pieces of highly permeable, saturable magnetic alloy which, when suitably energized by an alternating current fed through primary coils, induce in a secondary coil a signal whose frequency is twice that of the energizing current and whose magnitude is proportional to that component of the ambient magnetic field parallel to the axis of the secondary coil. Two such elements are mounted with their axes vertical and separated by a vertical distance of 1.2 meters. The difference between the voltages of the signals emitted by the two elements is proportional to the difference in magnetic field between the two elements. The upper element, being further from the ground, serves to cancel out diurnal variations and other extraneous magnetic disturbances.

The flux-gate gradiometer produces results more rapidly than does the proton magnetometer, for readings may be taken continuously. Also, direct readings in gammas, including sign, are obtained. It is, however, more difficult to set up, since the flux-gate elements are directional and must therefore be carefully matched and kept strictly parallel.

More recently (1964–1965) we have been experimenting with rubidium and cesium magnetometers developed by Varian Associates for the University Museum in a search for the ruins of archaic Greek Sybaris in southern Italy. The search is an experiment in large-scale exploration of an archeologically unknown area (*20*). From Greco-Roman accounts we know that the ruins must lie somewhere on or near the plain of the Crati River (an area of 80 to 100 square kilometers). And if the ruins lie on this plain, we know that they must be at least 5 meters below the surface. With the magnetometers and drills, we have located and mapped a ruin with Archaic, Hellenistic, and Roman levels extending over an area of about 3.5 square kilometers. Test excavations and drillings have disclosed archaic pottery over most of the area, but thus far only modest structures attributable to the period of Sybaris have been found. We can be relatively sure that this area, the Parco del Cavallo, is the site of Greek and Roman ports; but until we find massive stone buildings such as those at Paestum, Locri, and Metaponto, we cannot be certain that this is the site of the city of Sybaris itself.

The more sensitive optical-absorption magnetometers permit the detection of structures as deep as 5 to 6 meters below the surface. Preliminary tests at Sybaris during the fall of 1964 (*21*) with a rubidium magnetometer originally designed for space research demonstrated that the high sensitivity of the instrument (maximum, 0.01 gamma) could be utilized in archeological prospecting and that it was now possible to detect archeological remains lying at least 5 meters deep. However, the original instruments were not sufficiently portable for practical archeological work, and the results appeared as line graphs which then had to be laboriously converted to grid plots of magnetic contours for interpretation in terms of buried features. Varian Associates, in collaboration with the University Museum, then designed and built a light-weight mechanism for the conversion and display of detected frequencies as numbers, and substituted cesium for rubidium, thereby decreasing the effect upon the sensors of changes in their orientation.

The operation of the cesium and other optical-absorption magnetometers is based upon the Zeeman effect, in which the atomic energy levels become split into various sublevels whose separations depend on the total intensity of the ambient magnetic field. Optical pumping is required in order to detect this proportional splitting and involves the excitation of electrons into metastable states by the absorption of appropriate electromagnetic radiation. When "pumping" is completed, the pumped electrons are redistributed to lower levels by stimulation from a radio frequency corresponding to the difference in energy between the split levels. The resultant frequency detected by the instrument, therefore, is dependent upon the magnetic intensity in the vicinity of the sensor. This frequency is then related to a reference oscillator within the instrument, and the readings, in gammas, appear directly in digital form with the use of one sensor.

Diurnal variations and other extraneous changes in magnetic intensity require the use of an additional sensor in order to utilize the sensitivity of the instrument; the difference between two sensors is then read, rather than the absolute field as measured by one sensor. (Alternatively, two readouts might be synchronized for simultaneous readings.) One possibility is to carry two sensors, one a fixed distance above the other; but the fact that the structures of 6th- or 7th-century B.C. Sybaris are 5 or 6 meters underground would require that one 3-kilogram sensor be carried, ideally, 5 meters above the other. To avoid this ponderous prospect, one sensor was placed in a fixed position with a 100 meter cable leading to the instrument; using this difference mode of operation, the fixed sensor became the reference oscillator and the base reading was 80,000 units (*22*).

The advantage of this "difference" mode of operation is that, as the position of the movable sensor is changed, readings are affected only by the underground anomalies and are not influenced by diurnal or transient fluctuations in the magnetic field. Also, by placing a small anomaly such as a compass near the fixed sensor, it is possible to relate each succeeding fixed station to the previous one; if a reading of 10 units pertained in one field, the same reading in the next indicated the same conditions of magnetic contrast. And, because of the "absolute" feature, readings could be recorded directly in a notebook oriented in the same direction as that in which the grid was traversed.

It was found convenient to make large grids, usually within the boundaries of fences or hedgerows, with lines at 5-meter intervals and readings every 2 meters (measured in paces) on the lines. Readings appeared at a maximum rate of every 1.5 seconds (a comfortable pacing rate) and were entered

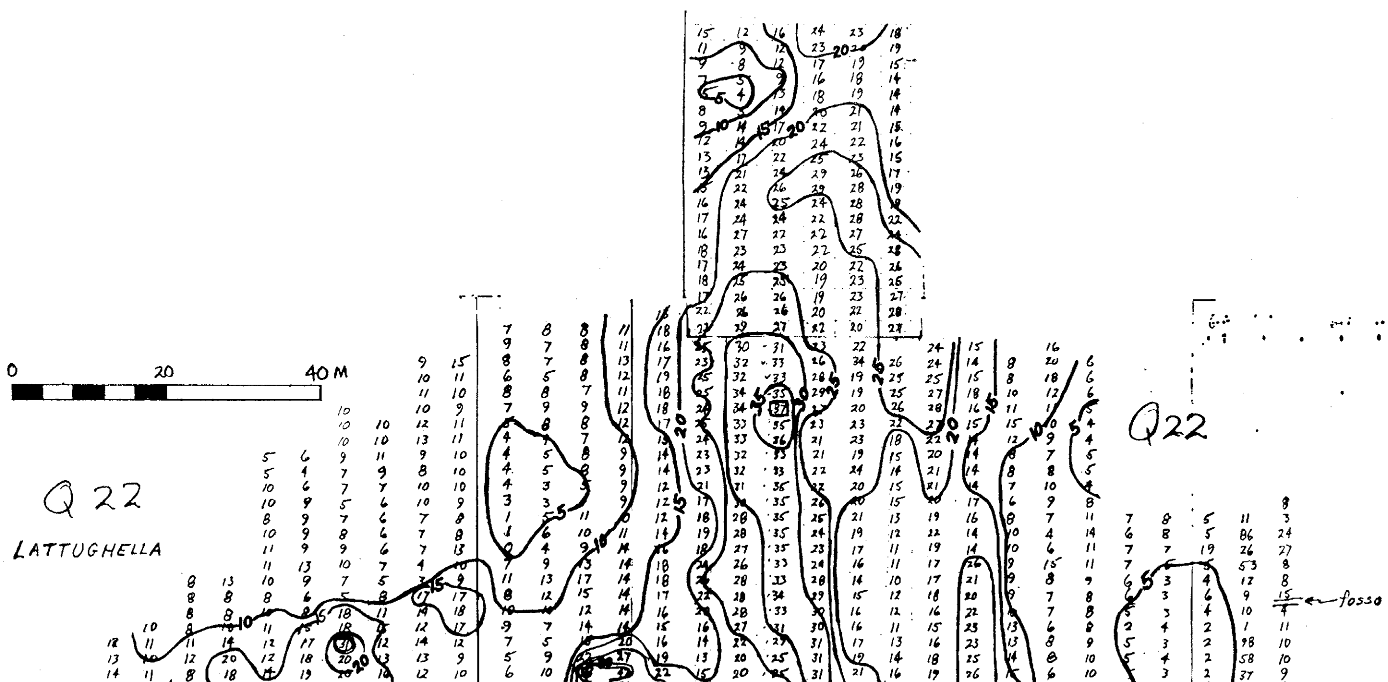

Fig. 7. Grid (or *Q*) 22 made with the cesium magnetometer. Contours of equal magnetic intensity are shown in "differential" units (1 unit 0.5) and are drawn at intervals of 5 units. The grid has been photographed from the original data and shows also the numbers as recorded in the field notebook. The location of Excavation ("Scavo") No. 1 is also shown. The most prominent magnetic anomaly is approximately 30 meters northeast of the excavation.

in the notebook on a scale of 1:400; approximately 5000 square meters could be surveyed in an hour. When the grid was completed, the pages of the notebook were pasted together in proper orientation and lines of equal magnetic intensity drawn directly. Examples of grids (Nos. 1 and 22) are shown in Figs. 6 and 7, and their locations are indicated on the map in Fig. 5.

All instrument surveys present the problem of interpretation of the anomalies detected by the instrument. Only a few are as readily understandable as is the plot shown in Fig. 8, the result of a Geohm survey made over the hospital foundations at Fort Lennox, Ile-aux-Noix, Quebec (*23*). These walls were at least 50 centimeters wide and lay less than 50 centimeters deep. The foundations are perfectly outlined in the plot, the two hearths are clearly indicated by areas of closely spaced contours, and excavation revealed that the bulge at the northern end represented a doorway.

In many areas, however, large-scale excavation is impractical, even though it is reasonably certain that the anomalies detected represent archeological features. This is particularly true on the plain of Sybaris, where the water table is but 1 meter below the surface, 4 to 5 meters above the archeological deposits sought. On such alluvial plains relatively free of natural rock, a jointed rod will confirm the presence of suspected features and provide some indication of their depth. Drilling is slower, but the potsherds and chips of construction materials brought up provide more information than do the rod explorations. And the use of a vehicle-mounted drill with forced water circulation makes it possible to distinguish between stone foundations and thin deposits of roof tile or other friable materials.

The interpretation of deep anomalies detected with the cesium magnetometer shown on the map in Fig. 5 is based on a series of drillings and one test excavation. The anomalies detected and assumed to represent structures (see Figs. 6 and 7 for examples) were predominantly magnetic, whereas the foundations of the archaic Greek structures are expected to consist of nonmagnetic stones and blocks. Those buried at shallower depths, such as the long wall sensed with the proton magnetometer in previous seasons, were almost entirely antimagnetic. Excavation 1 in 1964 and 1965 revealed massive deposits of roof tiles at a depth of 4 to 5 meters overlying small crude stone walls. From prior measurements on similar materials (*24*) we may estimate the following values (in electromagnetic units per cubic centimeter) for magnetic susceptibilities: stones, approximately 2.8×10^{-4}; deep clay, 4.0×10^{-4}; and roof tiles, 41.6×10^{-4}.

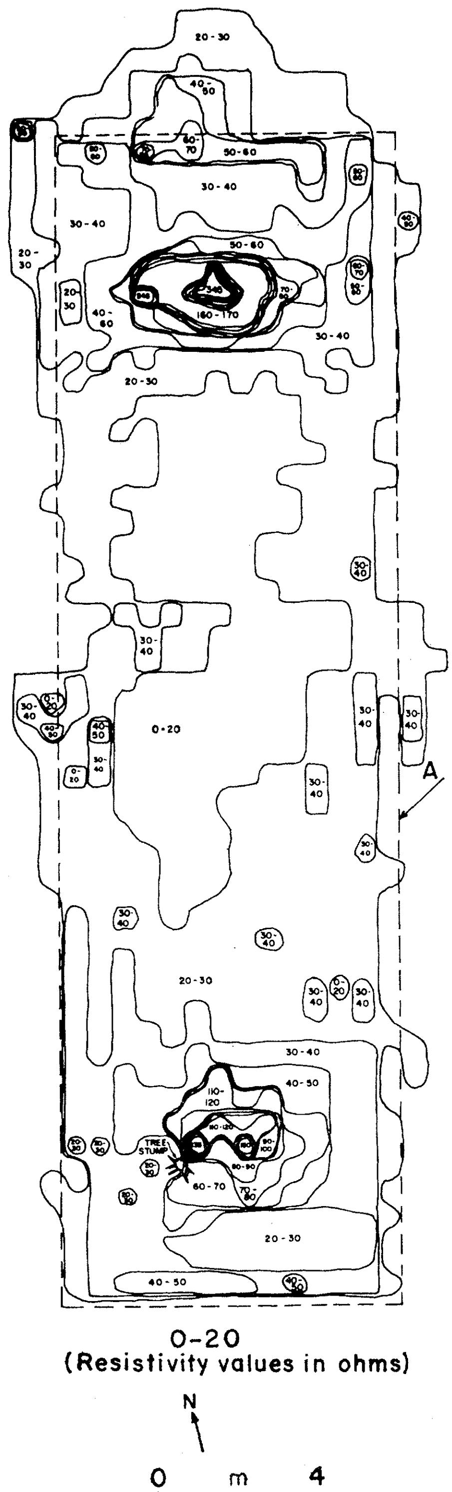

Fig. 8. Resistivity survey made with the Geohm over hospital foundations at Fort Lennox, Ile-aux-Noix, Canada, June 1964. Dashed lines represent outside edges of the wall foundations (8.5 by 30.8 m).

If we assume that the large anomaly northeast of Excavation 1 in Fig. 7 is caused by roof tile deposits with a breadth (t) of 10 meters, a length of 80 meters, and a thickness (d) of 0.4 meters at an average depth (r_0) of 4.5 meters, then we may envision a model of these deposits as a magnetized sheet of permeability μ_2 buried in a medium of permeability μ_1 in a field H_1 which had previously been uniform (see Fig. 9).

If the boundary conditions are $B_1 = B_2$ (normal component of B continuous), $\mu_1 H_1 = \mu_2 H_2$, and $H_2 = \mu_1 \mu_2 H_1$, and the magnetic sheet is replaced by the equivalent "surface" current i surrounding it, then

$$H_1 - H_2 = i/d, \quad i = d \, \frac{(\mu_2 - \mu_1)}{\mu_2}$$

At the surface, the currents i then give additional fields

$$H = i/2\pi r = \frac{d(\mu_2 - \mu_1)H_1}{2\pi\mu_2\sqrt{r_0^2 + (t/2)^2}}$$

These add, to give an anomaly in the vertical direction,

$$H_v = \frac{2}{\sqrt{2}} \, \frac{d(\mu_2 - \mu_1)H_1}{2\pi\mu_2\sqrt{r_0^2 + (t/2)^2}}$$

At a large distance, H_1 is unaffected. Therefore,

$$H_1/H_1 \simeq \frac{d(\mu_2 - \mu_1)}{\sqrt{2}\pi\mu_2\sqrt{r_0^2 + (t/2)^2}}$$

To evaluate this,

$$\mu_2 = 1 + 4\pi\chi_{rt}$$

and, where χ_{rt} and χ_c are the magnetic susceptibilities for roof tiles and deep clay, respectively,

$$\mu_1 = 1 + 4\pi\chi_c$$

We find, for this deposit of roof tiles,

$$H_v/H_1 \simeq 5 \times 10^{-5}$$

Since the vertical component of the earth's field in this region is about 0.37 oersted, the anomaly would be 1.9 gammas.

The magnetic field produced by this sheet has a negative value in nearby regions outside the immediate area, giving a contrast of approximately 3/2 times this value, or about 2.9 gammas, comparable with the observed effect. However, a similar mass of stones with magnetic intensity $\chi_s = 2.8 \times 10^{-4}$ electromagnetic units per cubic centimeter would give a much smaller antimagnetic anomaly ($H_v/H_1 \simeq 0.2 \times 10^{-5}$), or a contrast of 0.1 gamma, which would not be seen in the presence of the large magnetic anomaly.

This simplified analysis serves to explain why, on the plain of Sybaris, anomalies representative of archaic

Greek structures at depths of 4 to 6 meters appear as magnetic areas, and illustrates the difficulty of interpreting and, indeed, of finding non-massive stone structures. But, despite these problems, the cesium magnetometer is capable of effectively searching large areas for unknown sites, given a type of terrain in which archeological features are detectable as magnetic anomalies. We have now discovered that on certain other types of terrain, such as the highlands about the Sybaris plain, where there are individual pockets of magnetic soils, magnetometers cannot be used for survey.

Experiments with other instruments, such as seismic sensors, metal detectors, and sonic equipment, have not yet produced very satisfactory results. Seismic instruments generally detect little more than depth and contours of bedrock; metal detectors have too little depth penetration for archeological purposes; and sonic devices still have too many unsolved problems to be of practical everyday use. H. E. Edgerton of the Massachusetts Institute of Technology is experimenting with a "Boomer" system for the penetration of underwater sediments, and the University Museum has been working on a high-frequency device for use on land. In principle, both of these latter devices couple an electric impulse into the soil so that its reflection or refraction (or both) from an underground feature can be recorded and the structure can thus be located both vertically and horizontally. The major problem lies in producing a satisfactory coupling device which will permit a high-frequency pulse to enter the ground without great loss of energy and to penetrate to reasonable depths.

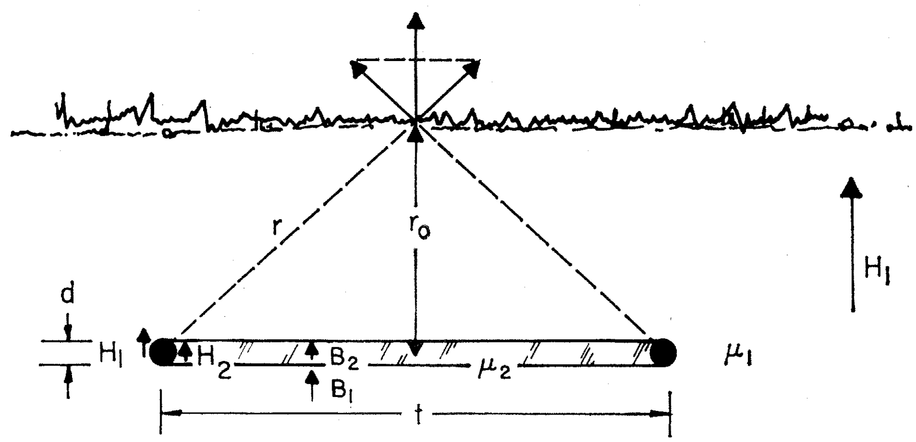

Fig. 9. Diagram for the calculation of the anomaly from the archeological deposit in Q22, plain of Sybaris.

Underwater Archeology

Technology of the postwar years has opened a new world beneath the sea as well as in space, and most of us are only now realizing that the sea holds some of the more promising future discoveries in archeology. Perhaps we failed to see the usefulness of scuba diving equipment in serious archeological research because it was first utilized in underwater exploration as a sport. Today, thanks to the application of many new devices for underwater exploration by such trained archeologists as George Bass of the University Museum, there is a well-defined discipline of underwater archeology which began when archeologists were trained to dive with scuba equipment and to apply the systematic techniques of land archeology to the study of underwater remains. It is now expanding rapidly with the development of equipment that permits more efficient underwater surveys and more effective methods of excavation and recording.

Scuba equipment made possible the systematic excavation of a Bronze Age wreck discovered off Cape Gelydonia by Turkish sponge divers, the discovery of Maya remains in Lake Amatetlan in Guatemala, the study of many Roman wrecks in the Mediterranean, the exploration of the sunken city of Port Royal in Jamaica, the investigation of the sunken port at Corinth, and the excavation of a Villanovan village at the bottom of Lake Bolsena in Italy. The next step was the development, in investigations of wrecks off Bodrum on the Turkish coast, of stereophotogrammetric mapping, which introduced a new precision and efficiency in underwater work.

Free-swimming archeological exploration, even at shallow depths, is painfully slow. Scuba divers can work for only short periods each day at depths of 45 meters, and work below that depth is unsafe. And it is now clear that more discoveries will be made when better exploration equipment is provided. To that end, the University Museum commissioned the Electric Boat Division of General Dynamics Corporation to build a two-man submarine specifically for underwater archeological surveying. The operators work inside at surface pressures, thereby eliminating many of the physiological hazards of scuba diving. The submarine can cruise at 7.4 kilometers per hour for as much as 8 hours per day, and to depths of at least 90 meters. Viewing ports and outside lights have increased the range and speed of undersea search, and the attachment of the stereophotogrammetric mapping equipment to the submarine has made possible the accurate mapping of sunken remains in a fraction of the time formerly required by scuba divers.

During the summer of 1965, Bass pioneered still another series of underwater exploration techniques off the coast of Turkey. A steel capsule known as the "Tow-Vane" was used to plane down to 83 meters for observation of the sea bottom. The operator inside the capsule worked at atmospheric pressure, breathing recirculated air to which oxygen was added, and maintained contact with the surface towing vessel by telephone. A closed-circuit television camera was also towed along the sea bottom by the surface vessel. Natural light was sufficient at 83 meters, and in clouded water the camera could often "see" better than the observer in the capsule. An Elsec proton magnetometer, adapted for undersea use by E. T. Hall of the Oxford Laboratory, was towed along the sea bottom in search of deposits of metal and pottery.

All these instruments functioned as intended and could be used to search the sea bottom for archeological remains. Nevertheless, specific wrecks known to be on the bottom in that area were not found. And from this we reach the conclusions that the sea is large, the wrecks are small, and the scanning range of the instruments is still too limited for rapid and easy exploration. But this sort of search is still in its infancy, and the development of these techniques is proceeding at such a rapid rate as to inspire considerable confidence for the future.

Analytical Techniques

The discovery and development of new tools for the analysis and identification of archeological materials is proceeding in many laboratories throughout the world, and only the barest outline of the work such tools are performing for archeology will be given here (*25*). Neutron-activation analysis, based upon nuclear transmutation caused by bombardment in a nuclear reactor, may be used for widely varying analyses—on blood and soil, surveying the Mohole, analyzing the suface of the moon, or for the nondestructive analysis of ancient pottery and metals. The Brookhaven National Laboratory has used neutron-activation analysis to demonstrate, with pottery from Italy and from Central America, that a detailed analysis of elements contained in the clays makes it possible to determine the source of the materials and perhaps the region of manufacture. For example, the fine orange ware found at Piedras Negras in the lowlands of Guatemala has been proved to have been fabricated from deposits located in the highlands.

The Research Laboratory for Archaeology and the History of Art at Oxford has reported on a number of techniques currently under investigation, which, like the neutron-activation method, can be used for both qualitative and quantitative studies of archeological materials directed at tracing the origin of manufacture, trade routes, the understanding of ancient technology, and the detection of fakes. These techniques include x-ray fluorescence, electric-beam x-ray-scanning microanalysis, beta-ray backscatter meters, and optical-emission spectrometry. The essential point, however, is that these are archeological tools recently derived, for the most part, from postwar atomic-nuclear development. And it is their large number and rapid rate of improvement which indicate the probable future impact upon archeological studies.

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23. Surveys at this site were conducted under the sponsorship of the Canadian Department of Northern Affairs and Natural Resources as a part of a training program for students in archeology.
24. We are indebted to M. J. Aitken, Research Laboratory for Archaeology and the History of Art, Oxford University, for these measurements.
25. Most of these are reported in *Archaeometry* **1** to **7** (1958–1964).

26. We thank the NSF for support of our thermoluminescence, C^{14} known age dating, and part of our instrument programs.

Structure of Biological Membranes

The unit membrane theory is reevaluated in light of the data now available.

Edward D. Korn

Membrane biochemistry occupies a central position in modern biology, second in importance, perhaps, only to biochemical genetics. Replication and organization are the significant differences between living and nonliving catalytic systems, and cellular organization is a function of membranes. In spite of the fact that many of the major activities of cells occur in, on, or through membranes, very little is known about their structure or the mechanisms of membrane-associated reactions.

One hypothesis for the structure of membranes that has been generally accepted is the concept of the unit membrane as proposed by Robertson (*1*). This theory is a skillful interpretation of electron microscopic and x-ray diffraction data in terms of the ingenious paucimolecular model of membrane structure deduced by Danielli and Davson (*2*) from permeability, surface tension, and electrical conductivity measurements.

The unit membrane theory has two aspects. First, there is one basic structure to which all membranes, or most portions of all membranes, of all cells of all species conform. Second, this structure consists of a bimolecular leaflet of phospholipids whose nonpolar portions, mainly fatty acyl chains, are inwardly oriented perpendicular to the plane of the membrane. The polar moieties of the phospholipids comprise the external surface of the bimolecular leaflet and are covered by a layer of protein and, perhaps, some carbohydrate. It is understood that the com-

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